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CAUSE-AND-EFFECT RELATIONS WITH RESPECT TO DEFECTS IN BRICK FIRING IN TUNNEL KILNS

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The cause-and-effect relations in firing brick in tunnel kilns are investigated and the causes of defects depending on the rate of heat treatment of brick in the kiln are identified. Current gas burners do not satisfy the requirements imposed on firing velocity regimes. The kiln has to be upgraded: Vulkan-gaz burners should be replaced by state-of-the-art gas burners with automatic control of the heat regime of the kiln, and the thermal regime in the preparation zone of the tunnel kiln has to be improved.

The goal of saturating the ceramic brick market implies setting up new factories and reconstructing the existing brick factories, as well as the development of new thermotechnical machinery meeting the contemporary requirements on production efficiency.

The present study offers theoretical and practical analysis of defect causes and ways for improving production efficiency in firing brick in tunnel kilns at the Al'tair Works of Construction Materials.

A tunnel kiln with a flat roof of capacity 30 million bricks per year was designed by the Yuzhgiprostroii Institute and installed in 1990. The total length of the kiln is 134.7 m, width 3.5 m, and height 1.8 m, including a preparation zone, a firing zone with a hardening zone, and a cooling zone. Brick is heated by Vulkan-gaz gas-plasma heaters (95 heaters) installed in the tunnel kiln roof according to the temperature schedule shown in Fig. 1. The plot of the actual kiln performance is constructed by measuring temperatures in all zones of the kiln, whereas the theoretical plot is taken from [1].

The study of the temperature regime along the kiln indicates that the temperature in the preheating zone is below the prescribed value and in front of the firing zone it sharply increases, i.e., the rate of the temperature rise on this particular site exceeds the theoretical rate and the brick is subjected to an abrupt thermal shock, which impairs the quality of firing and increases the quantity of defects.

The analysis of the kiln performance included consideration of the following physicochemical processes:

- the technological process related to modifications of the physicochemical properties of initial materials and products in the course of heating and cooling;
- thermal engineering process ensuring the combustion of gas and heat exchange between heated gases and the surface of bricks (external heat exchange), as well as propagation of heat within the brick (internal heat exchange);
- the aerodynamic process that regularizes the gas motion across the section of the loaded kiln;
- the mechanical process responsible for the movement of materials in the kiln tunnel.

To achieve an appropriate technological process, all other processes should be subordinated to the former in order to ensure its optimum qualitative and quantitative parameters.

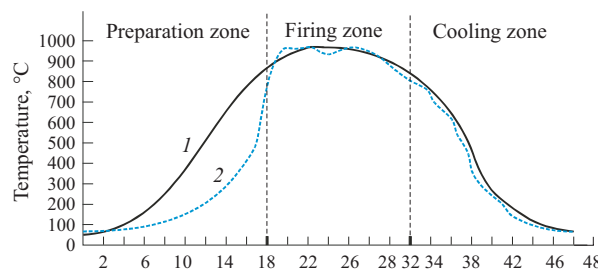
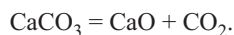


Fig. 1. Theoretical (1) and actual (2) temperature regimes of the tunnel kiln.

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The practice of brick production at different production stages shows that losses cannot be avoided. At the firing stage the losses can reach 2% of the total number of fired articles. The analysis of the factory production revealed the following defects and the reasons for their emergence in firing brick in a tunnel kiln.

Bulges. The clays used for producing bricks at the Al'tair Works contains impurities in the form of calcium carbonate CaCO_3 , which intensely dissociates in ceramic mixtures and emits carbon dioxide:



If a ceramic article in such a period is porous and gas-permeable, the dissociation of carbonates enhances the porosity of the fired product. If a liquid phase is formed inside the ceramic body before the start of intense dissociation of carbonates, the released carbon dioxide becomes the reason for the emergence of bubbles, swelling, and other defects. Such brick is unfit for application.

The cause of this defect is disturbance of the temperature-velocity regime in the preparation zone.

Ferrous impurities in the form of oxide compounds present in raw materials used in brick production at this particular factory determine the color of brick under firing in an oxidizing medium (excess of O_2). When fired in a reducing medium (shortage of O_2) at a temperature below 1000°C , the iron oxide compounds are reduced and, as they have a high reaction capacity, form low-melting ferrous glasses that facilitate the consolidation of ceramics. The gases released in this case cause swelling in the brick, if it does not have enough open porosity for the exit of gases. Such brick is unfit for service.

The cause of the defect is disturbance of the temperature process in the firing zone.

Nonuniform tint on the brick surface. The reason for this type of defect is increased moisture in the molded brick preform. The removal of hygroscopic moisture (i.e., drying of molded bricks) occurs within the temperature interval of $40 - 150^\circ\text{C}$. In this process a substantial amount of water vapor is formed, which under a rapidly rising temperature is released very intensely and may break the article. The heating of products in the kiln within the specified temperature interval should proceed slowly, since only in this case does final drying occur with an insignificant temperature gradient across the brick thickness without disturbing its integrity (without cracks or fractures).

However, in a slow drying cycle the following reactions have time to occur. Sulfur dioxide, which makes up part of flue gas, reacts with water and produces sulfuric acid reacting with calcium carbonate. In this case a calcium sulfate tarnish is formed on the brick surface, which makes the brick tint inhomogeneous.

In this case only the aesthetic properties of the brick are impaired and, therefore, it can be used in construction, but its price decreases significantly.

The reason for this defect is disturbance of the technological process in the preparation zone and poor control (or impossibility of control) of molded brick drying.

Metallic tarnish on bricks walls. The reason for the formation of metallic tarnish is the lack of oxygen in the air supplied to the gas burners to obtain a combustible mixture at the first stages of firing. When bricks are fired with an insufficient content of oxygen, FeO is formed, which leads to the formation of a metallic tarnish on the brick surface.

To eliminate this defect, one should carefully select an optimum regime of fuel combustion (gas : air ratio) and take into account the fact that a brick requires an excess of oxygen at the early stage of firing to get a deep homogeneous tint, whereas at the final stages of firing the content of oxygen should not exceed 0.3%.

The reasons for these defects are disturbance of the fuel combustion process and the technological process in the firing zone; lack of automated control of gas-air mixture feed; lack of combustion regime control.

Cracks or full destruction of product. This defect can be caused by the following reasons:

- noncompliance with the temperature regime within the interval of $40 - 150^\circ\text{C}$, where hygroscopic moisture is removed; under a fast temperature rise the release of steam is very intense, which may break the article;

- within the interval up to 575°C β -quartz transforms into α -quartz with the volume increasing by 2.8% and the opposite process takes place at the same temperature under cooling with the volume decreasing by 0.82%; a fast change in temperature during this modification transformation of silica may result in the fracture of brick;

- alumina Al_2O_3 and silica SiO_2 react in the temperature interval up to 800°C and form anhydrous mullite $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$; this heating period is related to the destruction of the crystal lattice of argillaceous materials and a substantial modification of the ceramic structure; a fast change of temperature is dangerous due to the possibility of crack formation.

The reason for the defect is disturbance of the temperature regime in the preparation zone and the cooling zone due to the absence of its automatic control.

Black core. Sawdust is introduced into clay as a combustible additive in the course of brick production. Sawdust in ceramic mixtures burns out in several stages. At a temperature of $350 - 400^\circ\text{C}$ volatile compounds are released and burn, whereas the coke residue burns out slowly at a higher temperature of $700 - 800^\circ\text{C}$. Its burning rate is in inverse proportion to the square of the article thickness and to a great extent depends on excessive air in flue gas. This combustion has to be completed while the entire ceramic material is porous and gas-permeable. If the process of consolidation of the peripheral shell of the brick is faster than the process of burning of the residual additives, the gas generates an increased pressure inside the brick and may deform the pliable

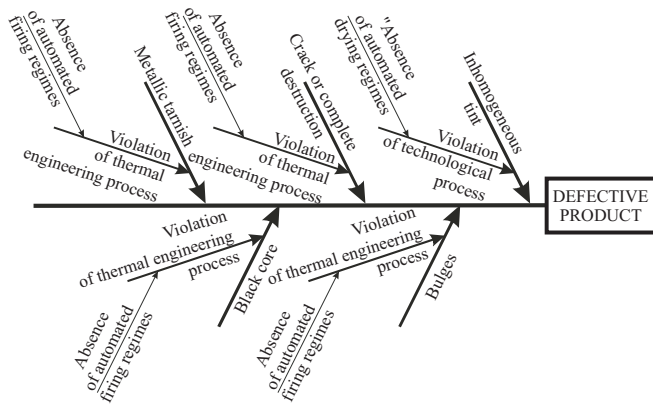


Fig. 2. Cause-and-effect diagrams for the causes of brick defects.

article, and the outburst of gases in certain places may initiate crack formation.

In this case a black core persists inside the brick, which is evidence either of the presence of unburned carbon, or the reduction of ferrous oxides to metallic iron. Such brick is unfit for service.

The reason for this defect is violation of the temperature regime in the preparation zone and the firing zone.

The above types of defects identified in firing brick in the tunnel kiln at the Al'tair Works have been systematized using the Ishikawa diagram [2]. In doing so, a cause-and-effect diagram has been constructed (Fig. 2). It can be seen that the defects in the products are mainly caused by noncompliance with the technological and temperature regimes of the kiln operation.

It should be noted that the heating systems in the brick-firing kiln of the Al'tair Works at the stages of heating, firing, and cooling do not fully match the physicochemical processes occurring in firing ceramics, and the old-fashioned gas burner design prevents maintaining the prescribed temperature regime over the entire cross-section and along the total length of the kiln tunnel.

The statistical analysis of defects (Fig. 3) shows that they are caused by the violation of the technological and thermotechnical processes due to the absence of automated control of gas-air mixture supply, unstable performance, and imperfect design of the gas burners, and the absence of the appropriate temperature regime in the preheating zone.

In order to avoid defects in firing brick at the Al'tair Works, we propose reconstructing the heating system to take into account all stages of the physicochemical transformations in brick firing. To do so, the existing gas burners should be replaced by modern burners with a wide variation range of the air excess ratio and a high dynamic impulse, which can create the required atmosphere inside the kiln and ensure a uniform temperature across the height and volume of a brick stack. One should pay special attention to the preparation zone, where currently the rate of temperature rise is insignificant and in front of the firing zone this rate exceeds the pre-

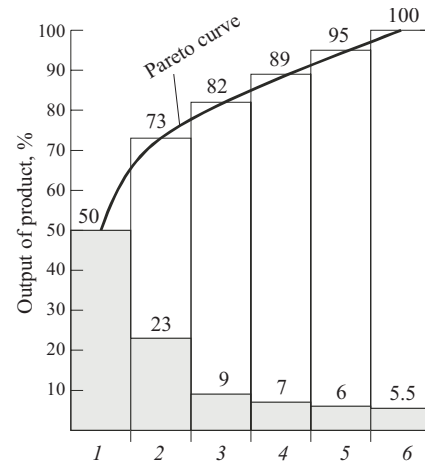


Fig. 3. Pareto diagram for types of defects: 1) metallic tarnish on brick walls; 2) inhomogeneous tint on brick surface; 3, 5) bulges; 4) crack or complete destruction of brick; 6) black core.

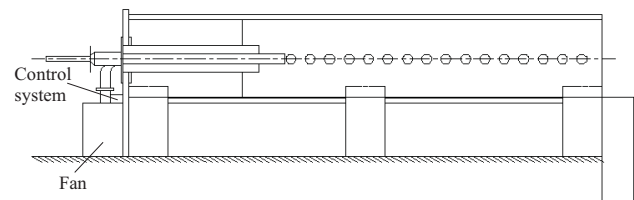


Fig. 4. Testing chamber.

scribed value. To solve these problems, burners should be installed in the preparation zone, especially in places where endothermic reactions proceed [3].

As the first stage of upgrading the tunnel kiln at the Al'tair Works, we have built a prototype plant (Fig. 4) that ensures stable operation of Vulkan-gaz burners.

The plant was tested in production, which established that Vulkan-gaz burners do not provide for optimum mixing of gas and air at the exit from the nozzle; therefore, the final combustion of the mixture occurs inside the chamber, far from the nozzle, and the flame is susceptible to random gas-dynamic flows in the working space of the chamber; the burners are hard to adjust [4].

After the adjusted burners was installed in the kiln, the number of rejected items in brick firing dropped by 15%, the unit fuel consumption decreased by 3%, and the kiln efficiency increased by 1.5%.

The analysis performed suggests the main directions for upgrading the kiln:

- install high-speed burners in a checkered layout in the preparation zone on both sides of the kiln to maintain the temperature within the required interval to fulfill the main technological functions, such as ensuring intense vortex motion mixing the heat carrier due to the high jet exit velocity, providing the required heat to the bottom rows of the brick

stack for uniform heating of articles across the stack height, and facilitating accelerated temperature increase in the material;

- replace old Vulkan-gaz burners by modern ones with controlled temperature and thermal heating regimes in a pre-set interval;

- install automatic electric device based on the PC-PLC technology (personal computer – programmable logic controller) complying with IEC61131 standard.

The obtained results can be used in other brick-firing kilns.

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